Title: Jet Substructure, by Accident

Date: Sep 18, 2012 01:00 PM

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Abstract: The LHC detectors are allowing experimentalists to look "inside" of jets and study the properties of these. Jet substructure gives us the tools to study boosted resonances that decay into jets. In this talk, I will discuss an extension of substructure techniques to beyond the Standard Model signals where reconstructing resonances may not be optimal, but these techniques still allow us to pick out these signals from a busy QCD environment.

Jet Substructure By Accident

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Perimeter Institute for Theoretical Physics

w/Tim Cohen, Mariangela Lisanti and Hou Keong Lou

Perimeter Institute, September 18th, 2012

So Far at the LHC

Found something Higgs-like (!!)

How about on the BSM side?

Still waiting for direct hints of BSM physics

But less model dependence in searches

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How about on the BSM side?

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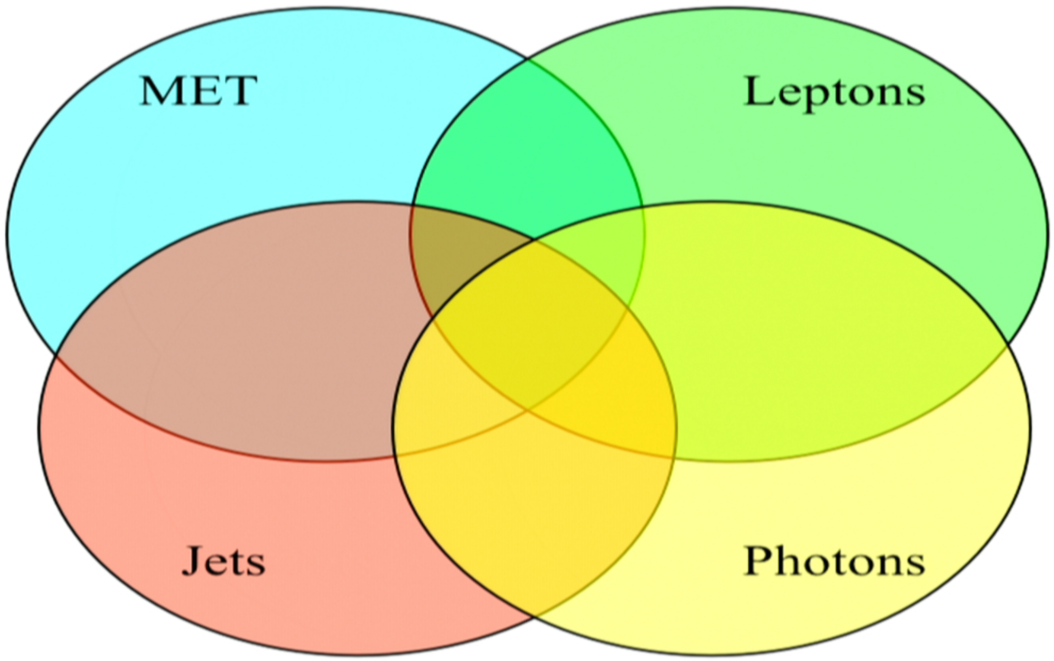
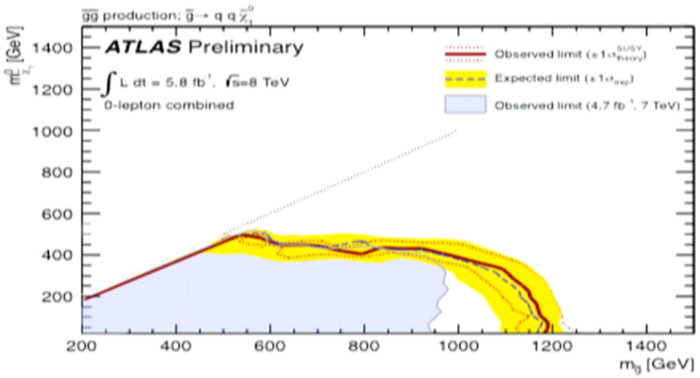
The Imprints of New Physics



So Far

$\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0$



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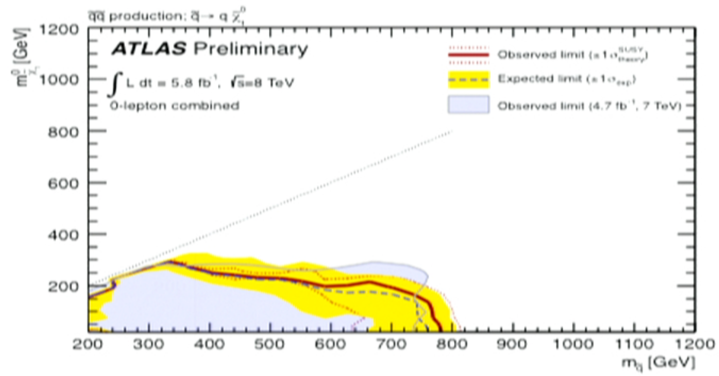
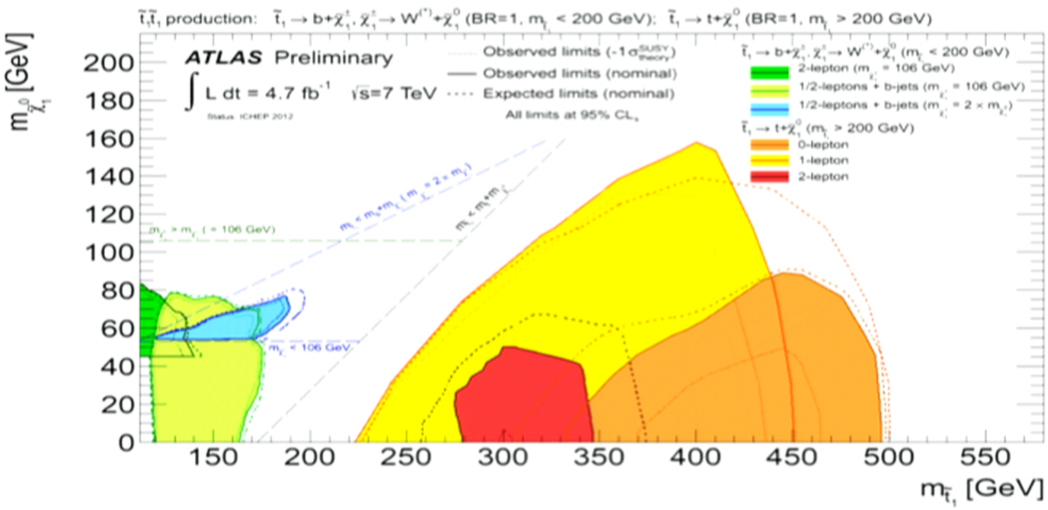


Limits on SUSY colored states into the TeV scale

Note however the simple decay topologies in limit plots

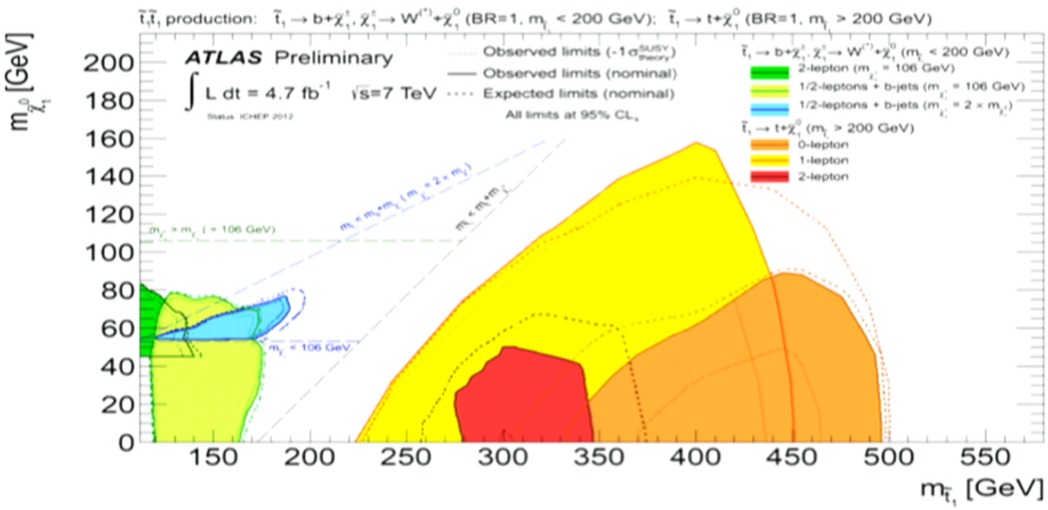
So Far



Stop searches

Interesting ground yet to be covered

So Far



Stop searches

Interesting ground yet to be covered

Outline

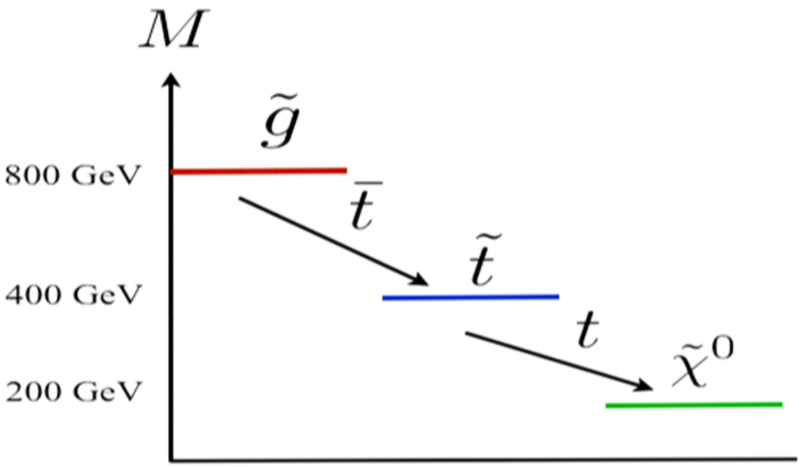
- High multiplicity signals and jet mass
- Jet substructure by accident

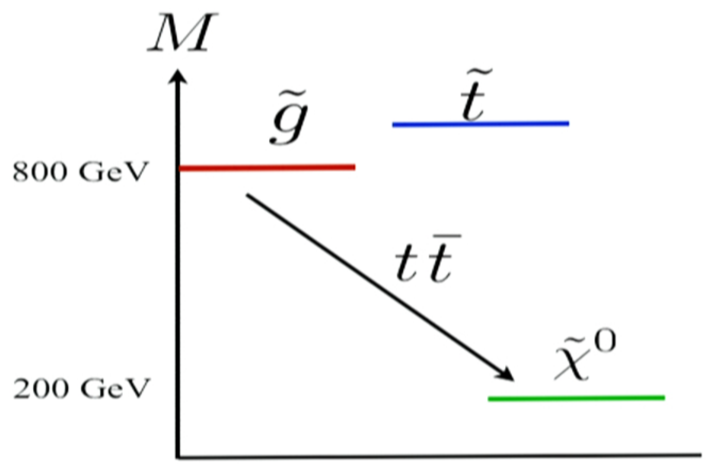
Natural SUSY Spectrum

Moderately light gluinos

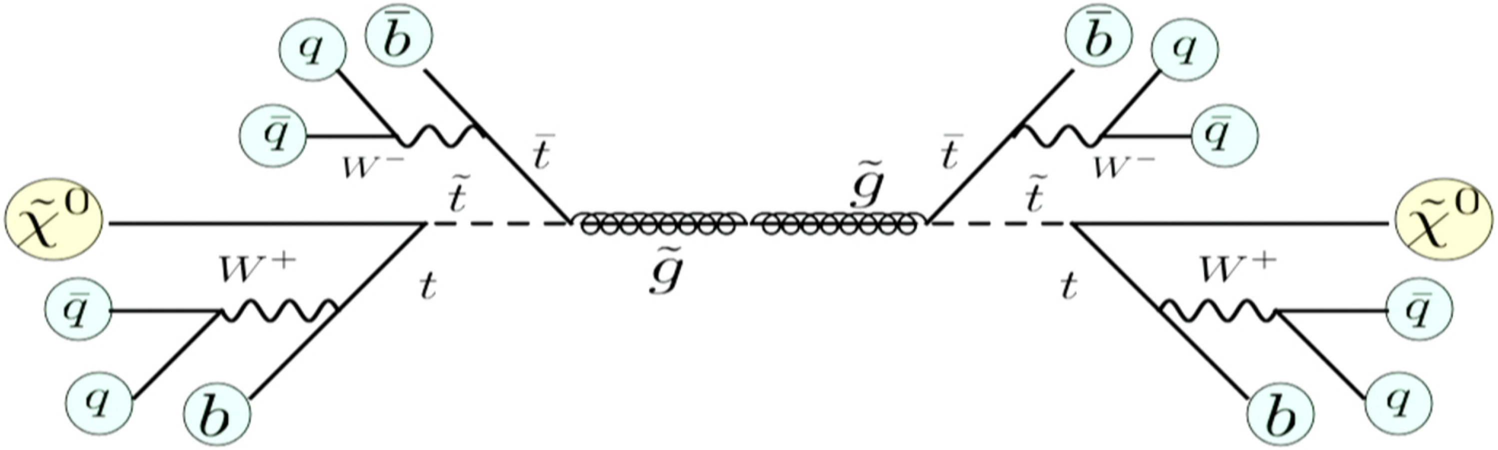
Light Stops

Light Higgsinos





Final Signature



Quite a Spectacular Final State

Not trivial to disentangle from background

High Multiplicity Backgrounds
No NLO
Tree-level is state of the art
Data Driven Extrapolation: $N \longrightarrow N+1$

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Heterogenous final states (+ b-tagging)
$4W : (8j, 0\ell) \longrightarrow (0j, 4\ell)$

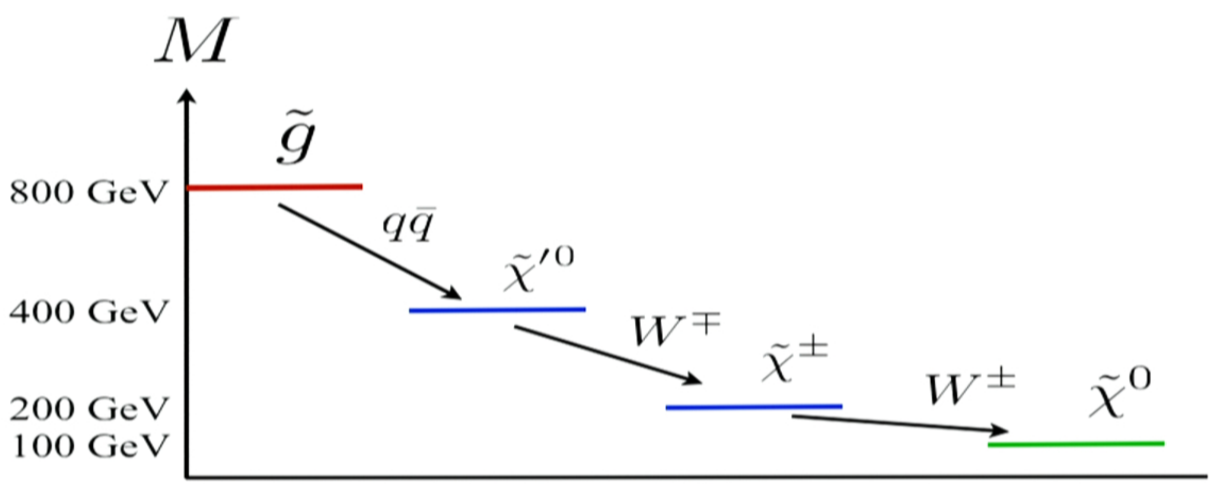
Jets can be accidentally grouped together
A variety of final state jet multiplicities

Isolated Jet P_T is Reduced
Easily fall beneath 50 GeV

Other Examples from SUSY

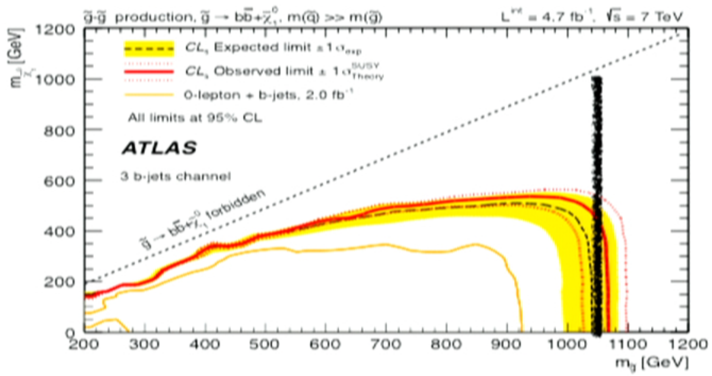
2 Step Cascade Decay

$$\tilde{g} \longrightarrow \tilde{W} \longrightarrow \tilde{H} \longrightarrow \tilde{B}$$

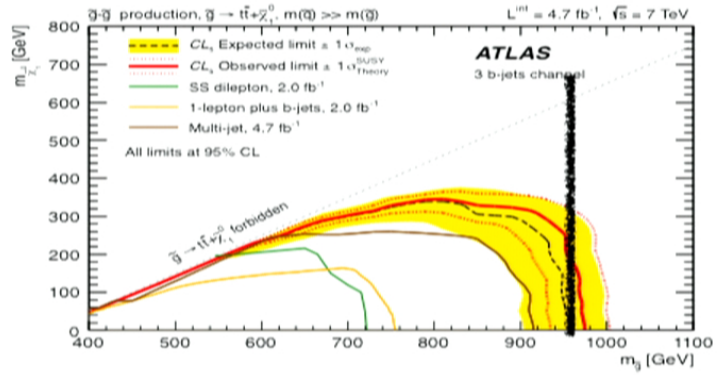


Third Generation SUSY Example
Estimated Optimal Reach at L=5/fb

$\tilde{g} \to b\bar{b}\chi^0$



$\tilde{g} \to t\bar{t}\chi^0$



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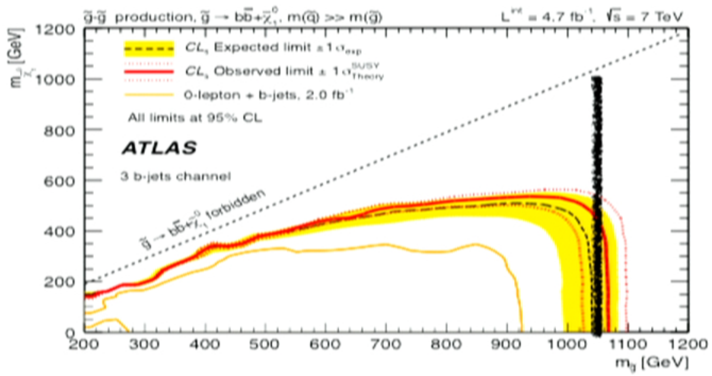

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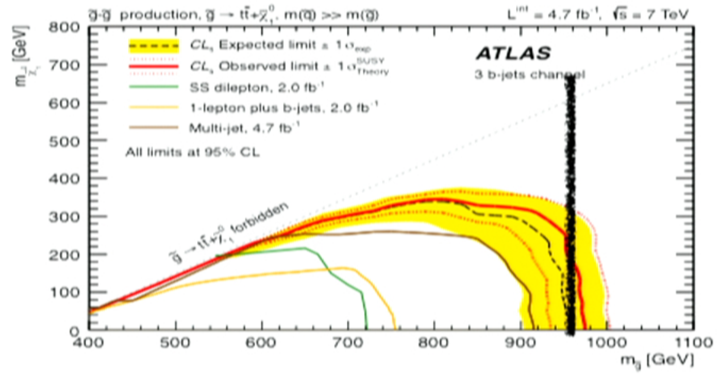

Recovering Sensitivity

Inclusive Approach
to gaining sensitivity to high multiplicity final states?

Why?
Requiring N jets requires O(N) cuts

Jets may have small p_T (accidentally forward)

Finite volume
Jets can be merged together

Go through undetected

"Standard" SUSY Searches

anti-k_T R = 0.4 to 0.6 jets (aka "thin" jets)

Lots of room for isolated jets

Good at separating high multiplicity
from low multiplicity

Instead cluster events into "fat" jets

e.g. anti-k_T R = 1.2

Only enough room for 4 to 6 jets

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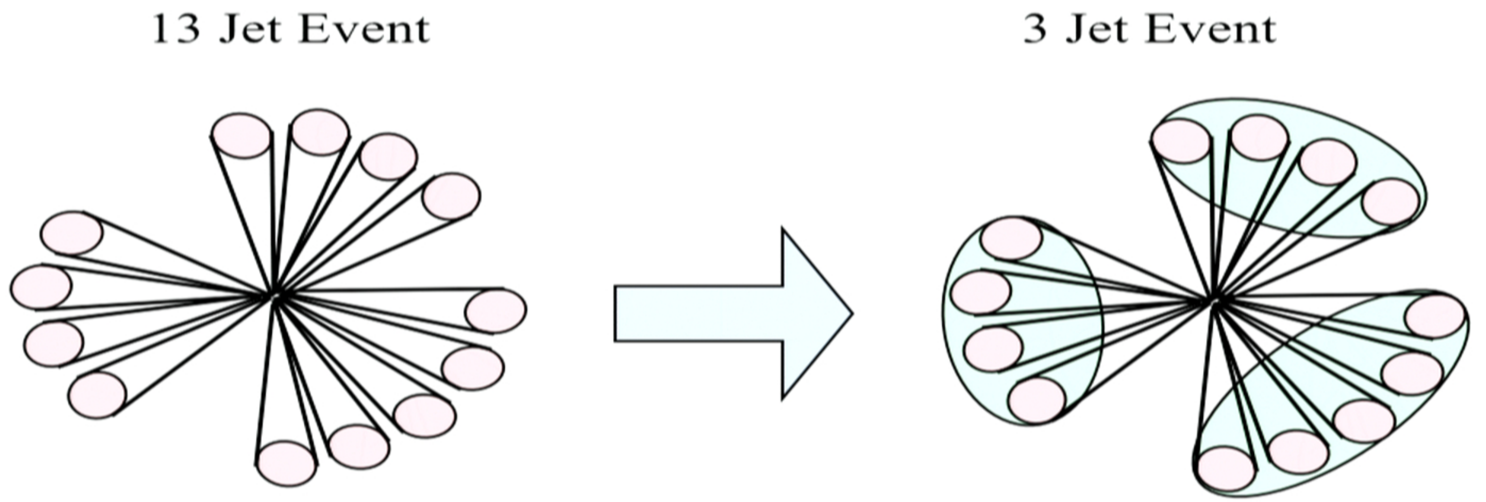
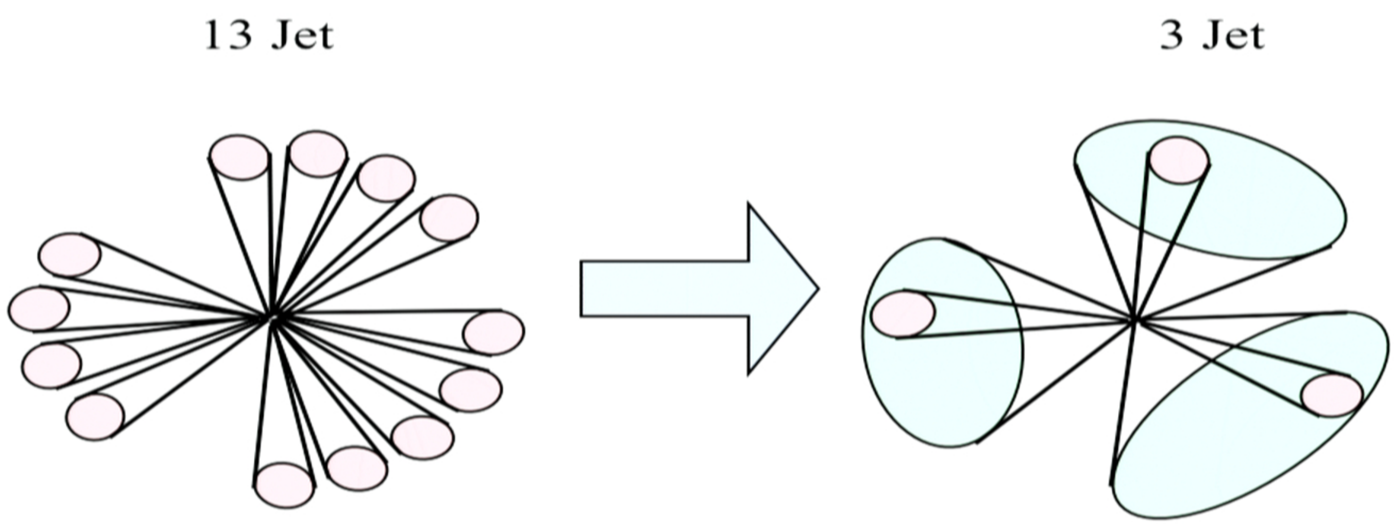
Aren't we losing the special feature of the event?



Typical QCD Background



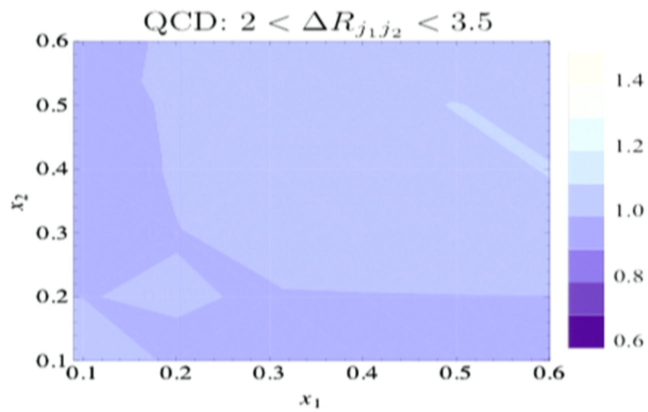
Are Jet Masses Correlated?

Each jet mass is approximately independent for QCD and V+jets

Consider m_j/p_T of leading two jets

$h(x_1,x_2)$

$$H(x_1,x_2) = \frac{h(x_1,x_2)\int h(x_1,x_2)dx_1 dx_2}{\int h(x_1,x_2)dx_1 \int h(x_1,x_2)dx_2},$$



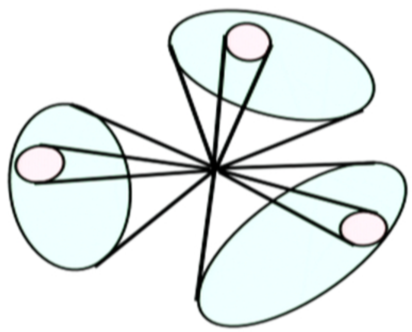
Z^0+nj with Pythia 6.4

~5% correlations

Slightly positive correlation

QCD jets only have small correlations

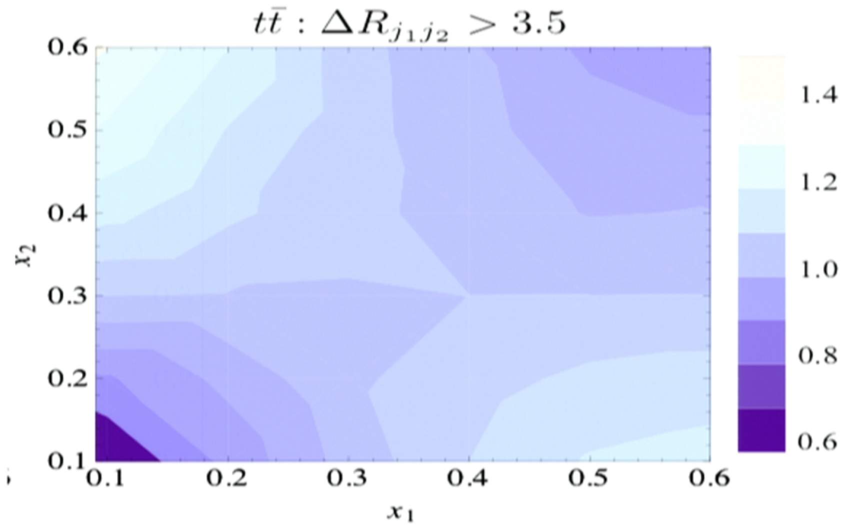
Data driven background predictions possible

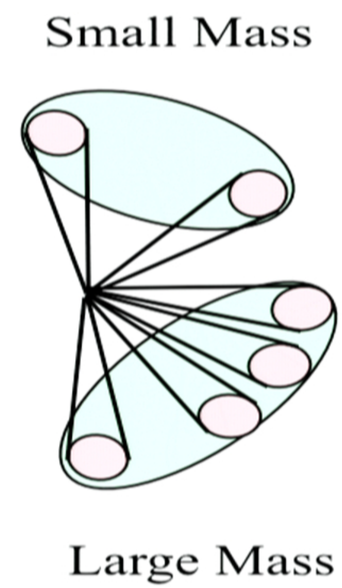


$$P_3(x_1, x_2, x_3) \simeq P_1(x_1)P_1(x_2)P_1(x_3)$$

Measure in one sample and extrapolate

Top Events (More Signal-Like)

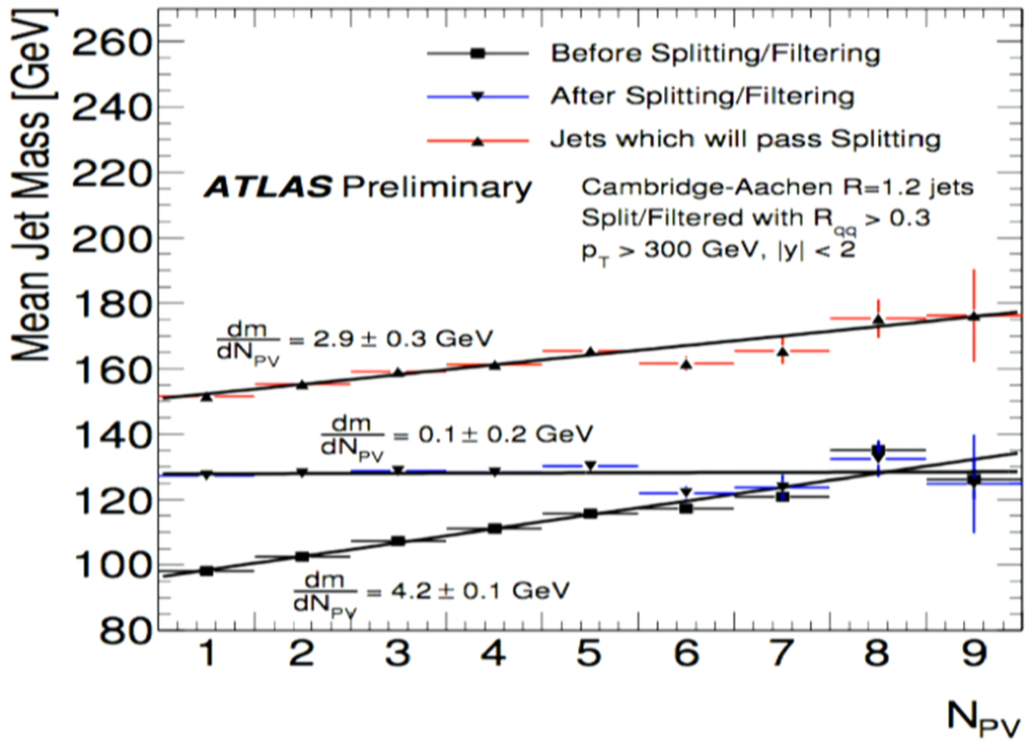




30% Correlations   Negative correlation

If one is massive,
the second is less likely to be massive

Fat Jet Masses at ATLAS



Introduce One New Variable

Sum of Jet Masses

$$M_J = \sum_{n=1}^{N_J} m_{j_n}$$

QCD jets have most of their mass generated
by the parton shower

Top events have their mass capped near 2 m_{top}

M_J as a replacement for H_T

$$H_T = \sum_{n=1}^{N_J} E_{T\,j_n}$$

$$H_T = \sum_{i=1}^{n_J} (p_{T,i}^2 + m_{j_i}^2)^{\frac{1}{2}} \qquad m_j = \kappa p_T R$$

$$\propto \sum_{i=1}^{n_J} \sqrt{\langle m_{j_i}^2 \rangle ((\kappa R)^{-2} + 1)} \simeq M_J \frac{\sqrt{1 + (\kappa R)^2}}{\kappa R}$$

Signal

$$\langle m_{j_i}^2 \rangle \propto p_{T,i}^2 R^2$$

Background

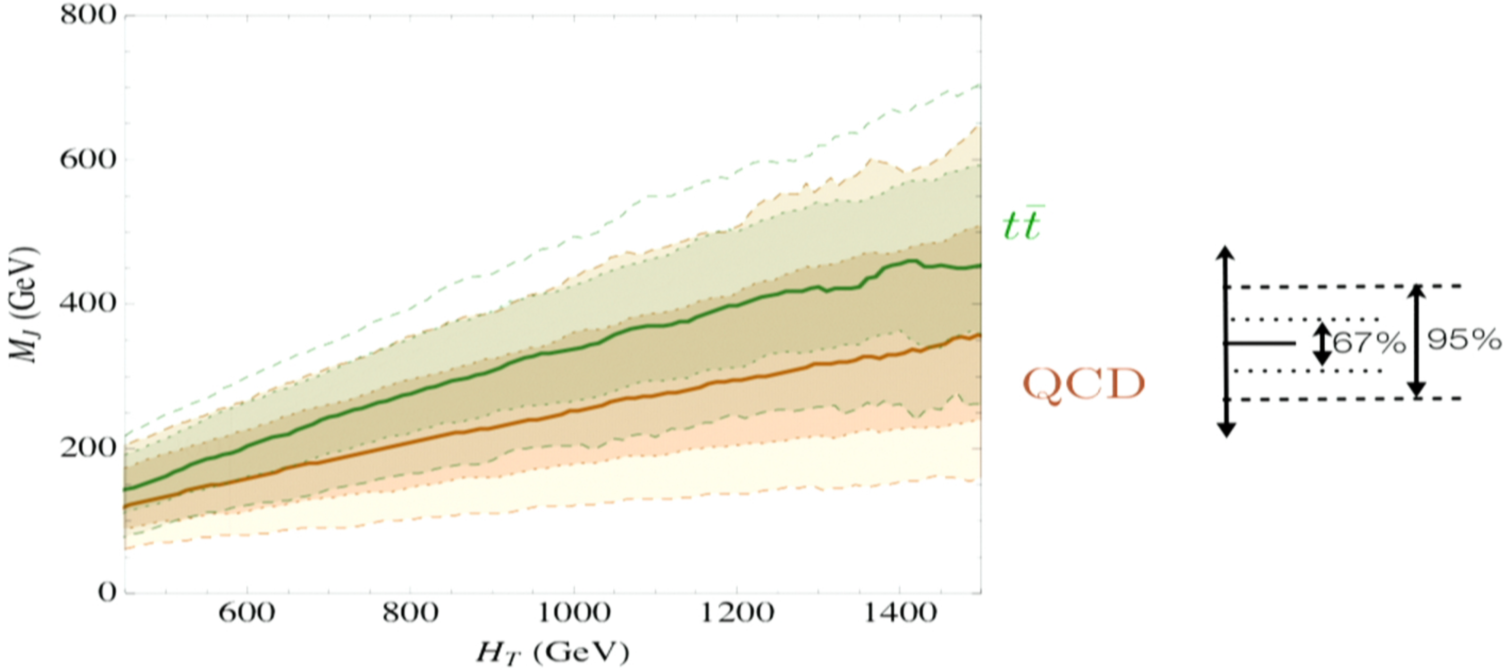
$$\langle m_{j_i}^2 \rangle \propto \alpha_s p_{T,i}^2 R^2$$

Signal typically has higher M_J for fixed H_T

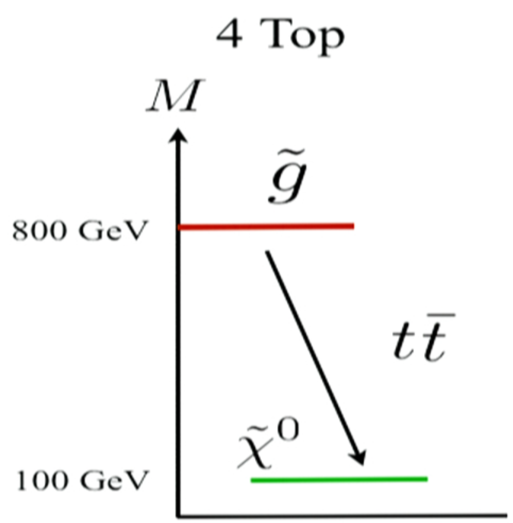
Never does worse

Treating Top as a Signal

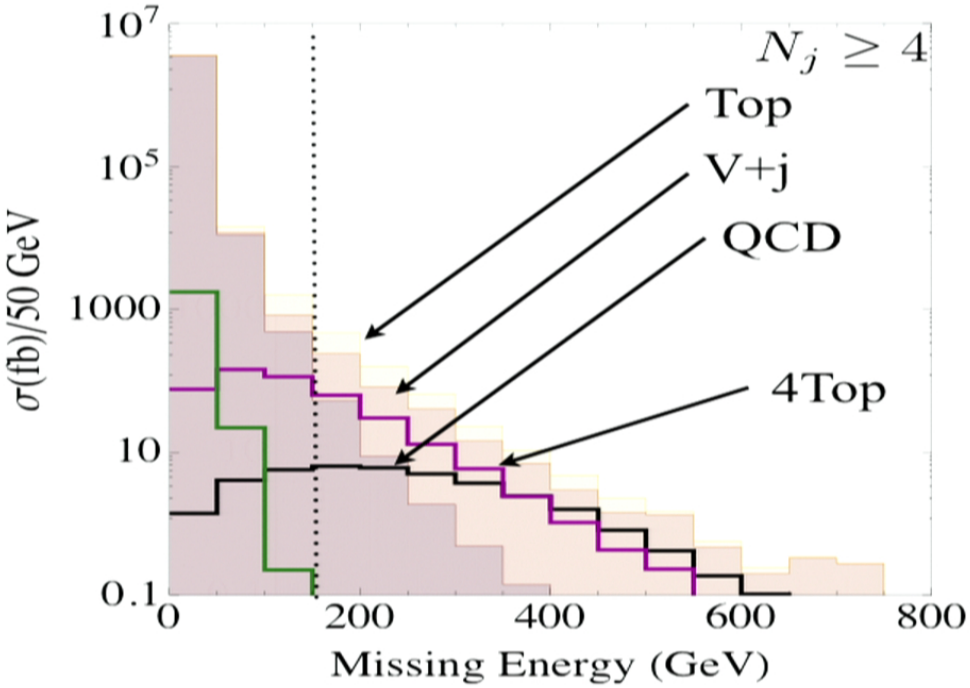
Real signal even steeper



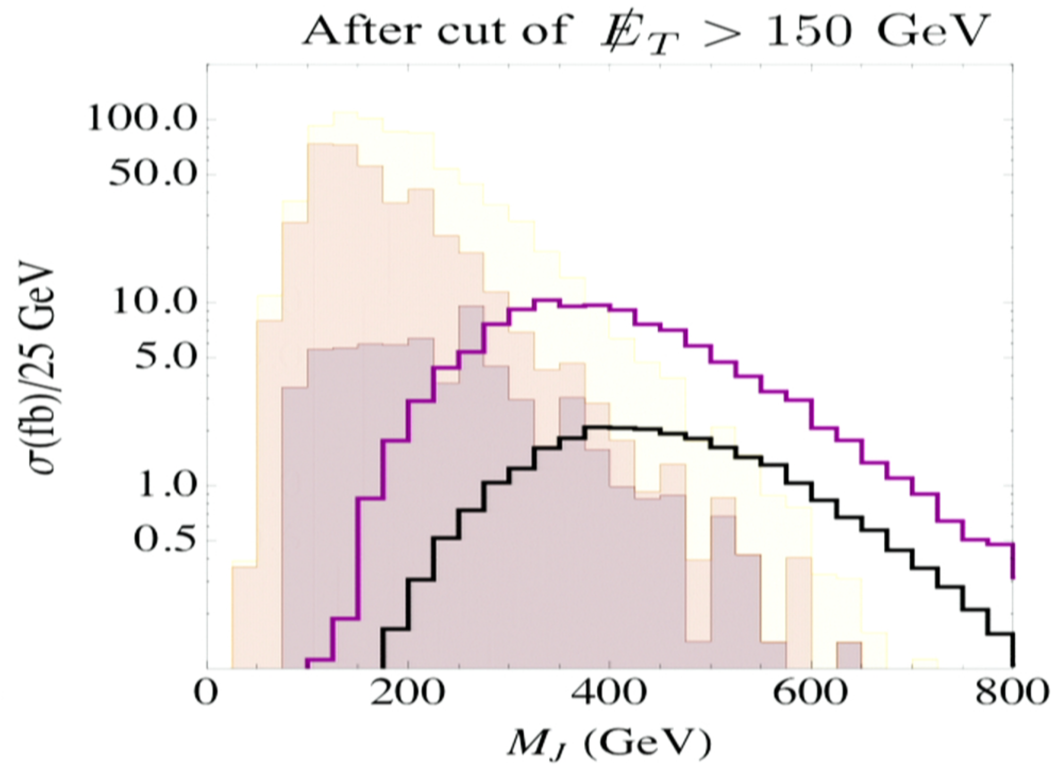
One Benchmark Model



Missing Energy Distribution



Gain at high M_J



Final Search Region

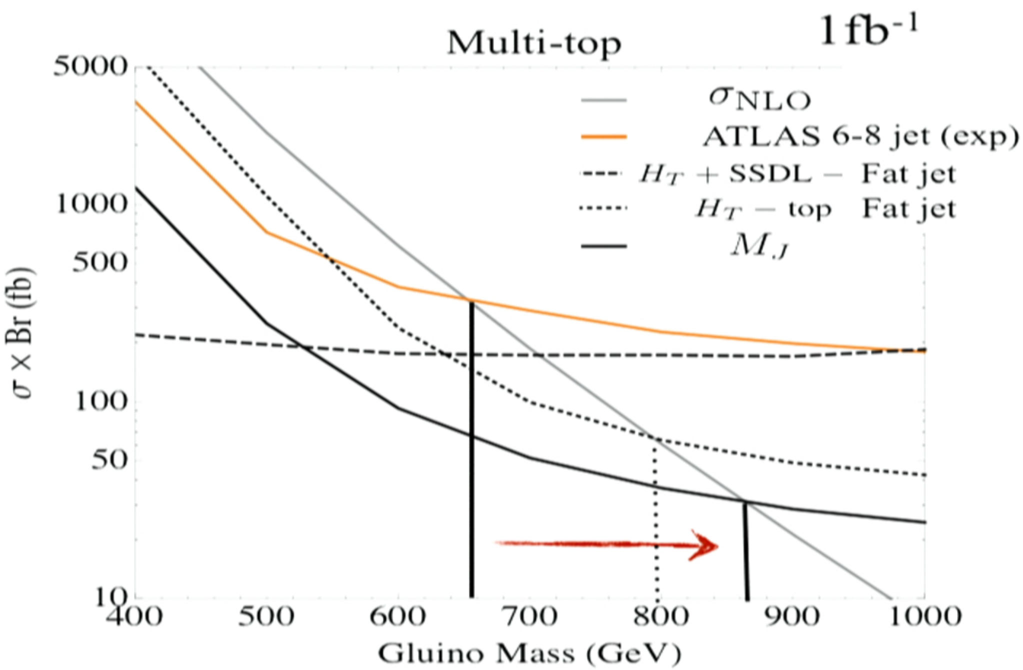
Compare to standard search regions

Search	N_j	R	Leptons	N_b	$\not{E}_T$ [GeV]	H_T [GeV]	M_J [GeV]
ATLAS	6-8$^+$	0.4	0	0$^+$	$3.5\sqrt{H_T}$	∅	∅
H_T+SSDL-top	3$^+$	1.2	SSDL	1$^+$	∅	300	∅
H_T-top	4$^+$	1.2	0$^+$	1$^+$	250	800	∅
H_T-cascade	4$^+$	1.2	0$^+$	0$^+$	150	1000	∅
M_J search	4$^+$	1.2	0$^+$	0$^+$	150	∅	450

Maximally Inclusive

No b-tags, no lepton vetos, low MET

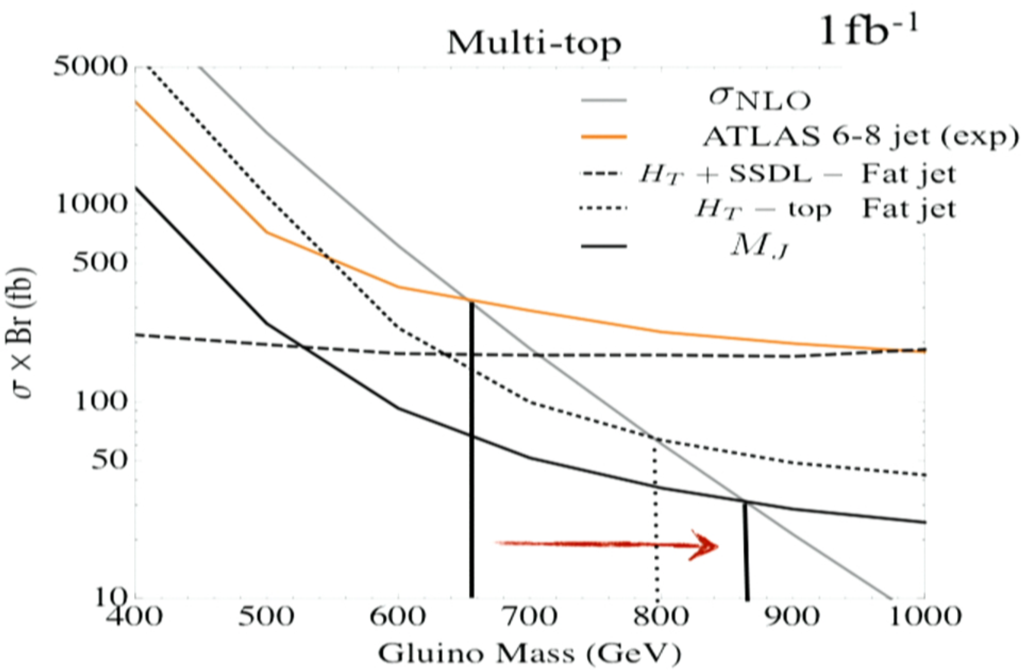
4 Top Estimated Limits



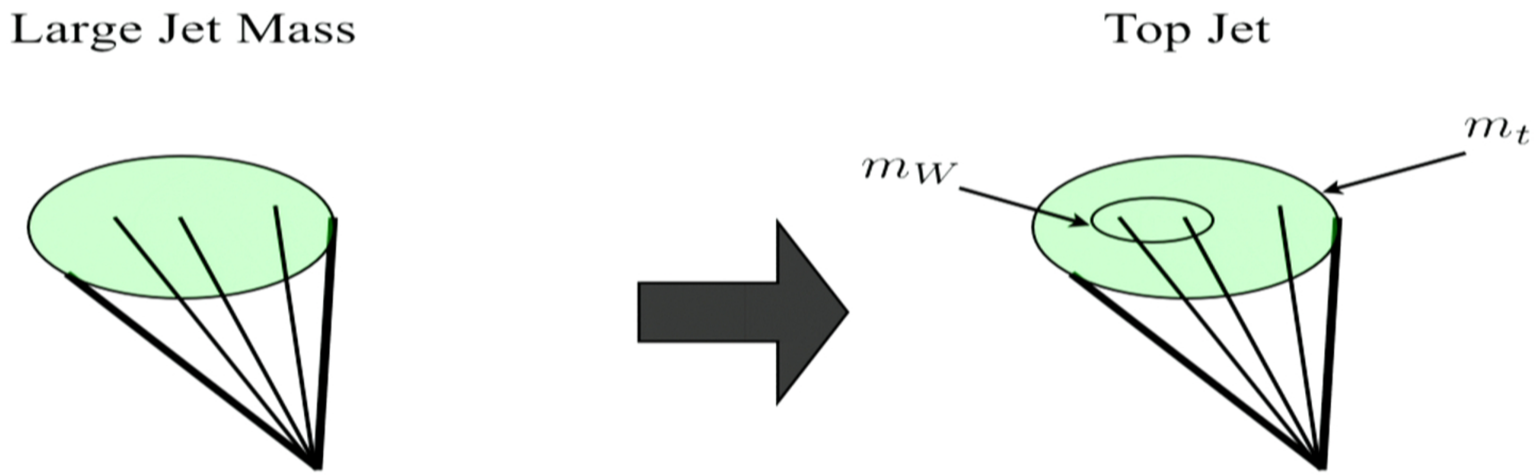
Outline

- High multiplicity signals and jet mass
- Jet substructure by accident ★

4 Top Estimated Limits



Jet Mass: The first stop to Substructure



(could still be faked by QCD)

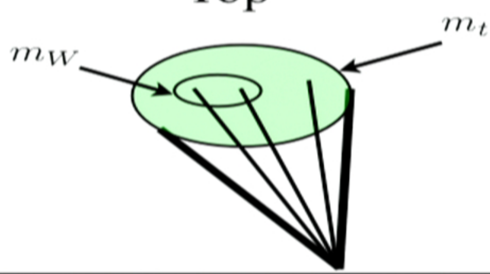
Jet Mass: The first stop to Substructure

To reconstruct mass peak
need the decaying particle to be quite boosted

Typically need $p_T > 2m$

if decay products are to be within a R$\sim$ 1 fat jet

Top



$p_T > 400$ GeV

Jet Substructure in BSM Physics

SUSY 4 top example discussed
Has peaks

Reconstructing all 4 tops requires high S_T event

Signal cross section falling rapidly with pT
So efficiency for reconstruction may be too small to be visible

But these are spectacular events (4 tops!)
No hints of this in the fat jets?

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Jet Substructure in BSM Physics

Approach:

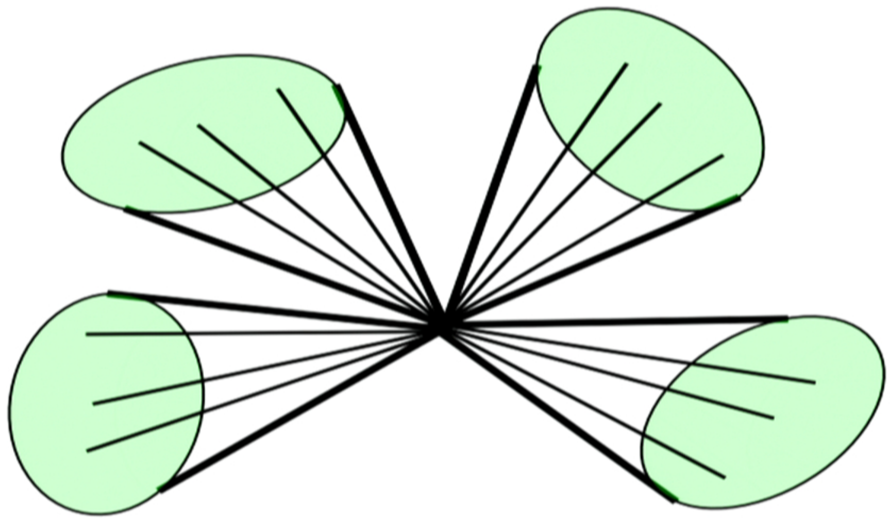
Look for (sub)structure in jets
(without reconstructing mass peaks)

Instead look for multiple multi-prong jets

This feature is a hint of a busy BSM final state

Jet Substructure in BSM Physics

The 4 top signature generates a large M_J, some MET
and multi-prong jets

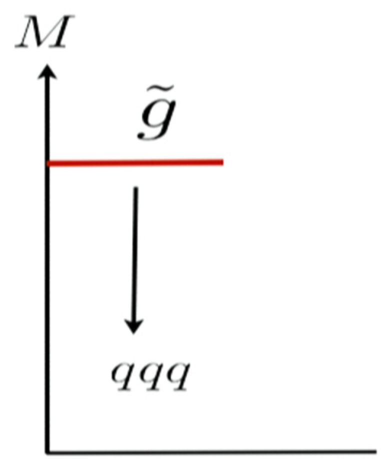


Instead test this on Non-MET Signal

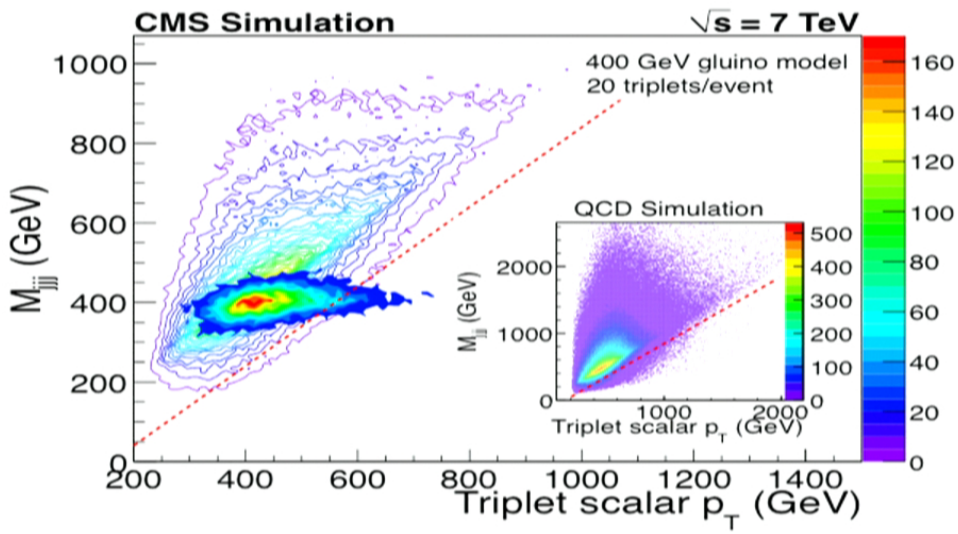
Not all theories have MET

One Benchmark Model

Baryonic RPV

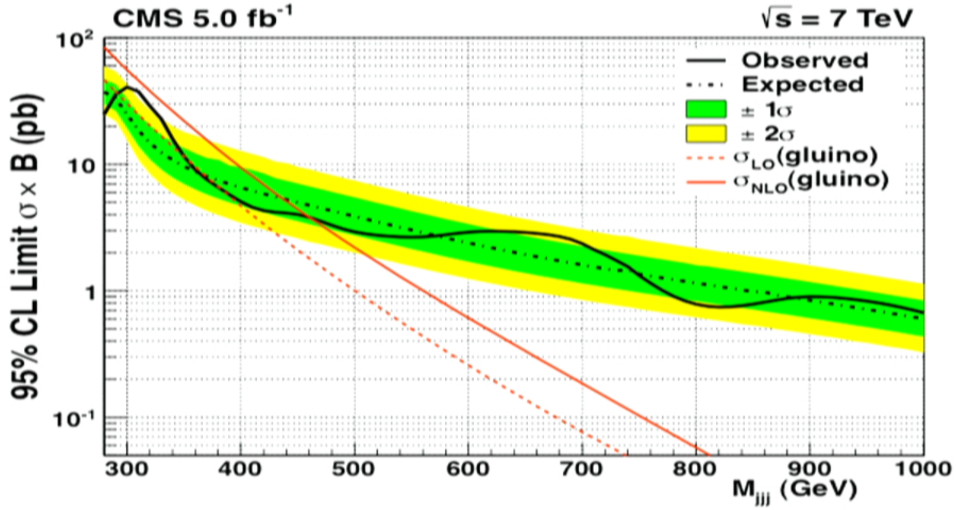


Three-jet resonance search by CMS



For a resonance analysis using substructure see Brian's talk

Three-jet resonance search by CMS



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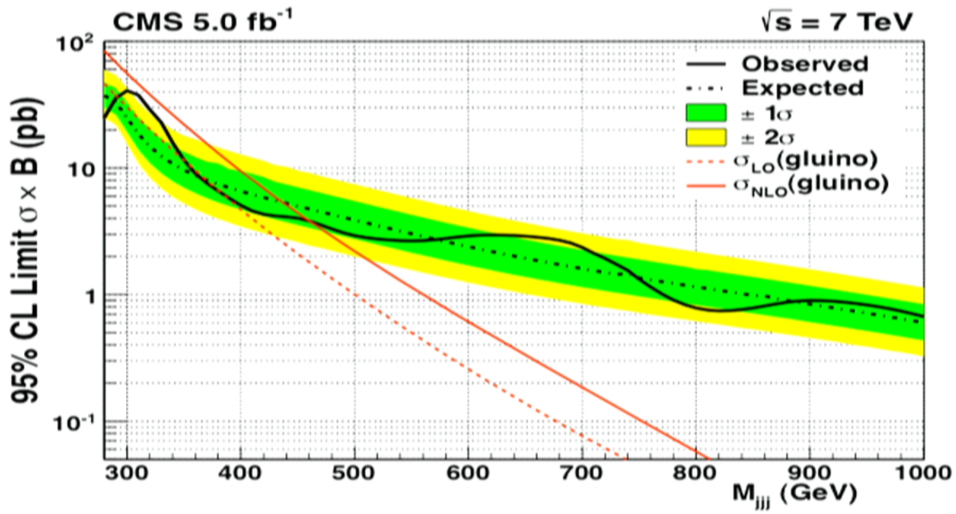

Test accidental substructure idea on Non-MET Searches

Use jet-shape Nsubjettiness

$$\tau_N = \frac{1}{d_0} \sum_{i \in \mathrm{jet}} p_{T,i} \min(\Delta R_{1,i}, \Delta R_{2,i}, \ldots, \Delta R_{1,N})$$

$$d_0 = \sum_{k \in \mathrm{jet}} p_{T,k} R_0$$

$\tau_N \to 0$ Jet is N-pronged

$\tau_N >> 0$ Jet is at least N+1-pronged

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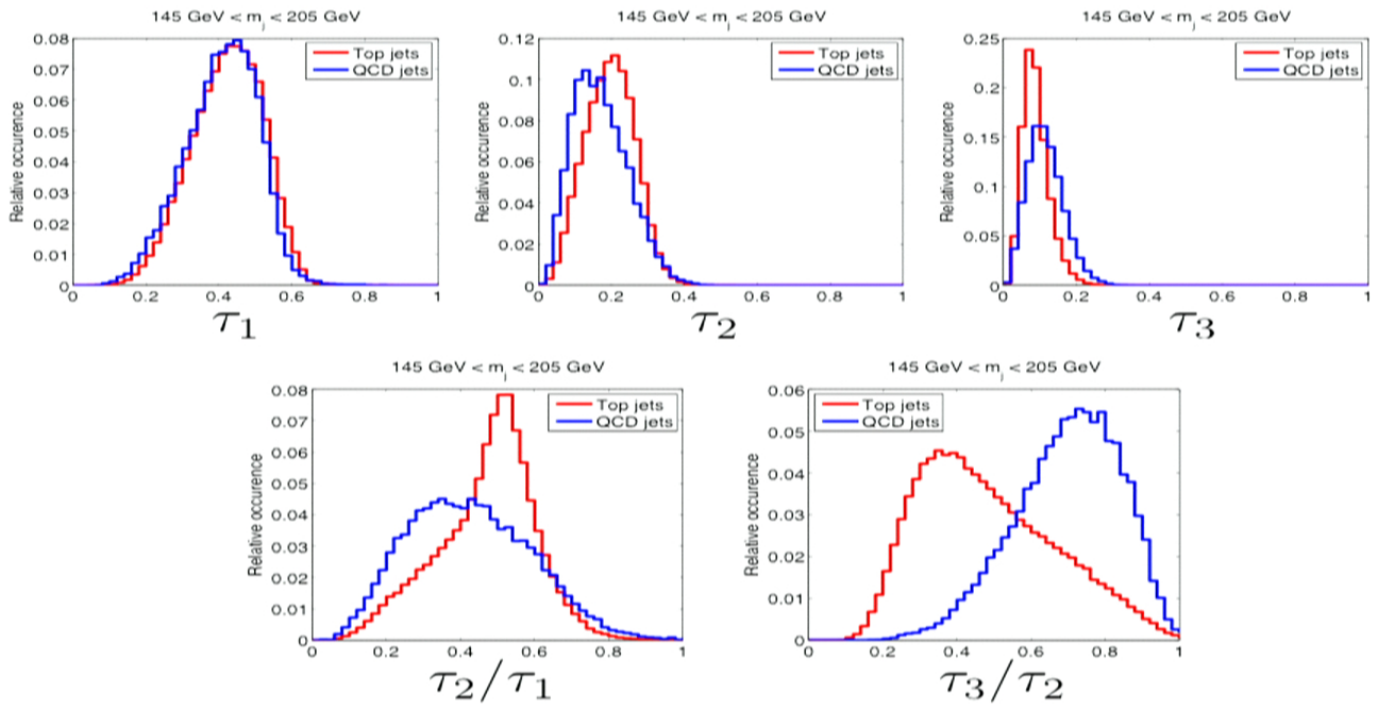
Nsubjettiness on Top Reconstruction

hep-ph/1011.2268



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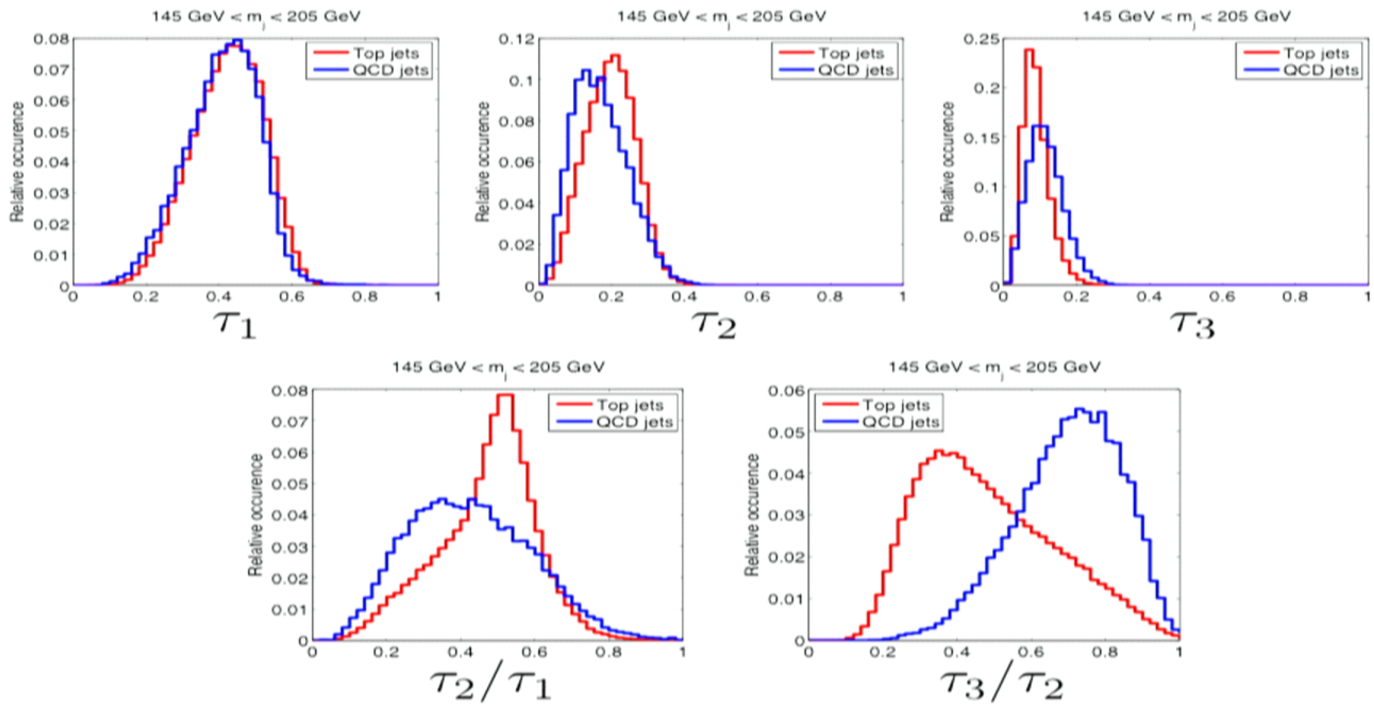
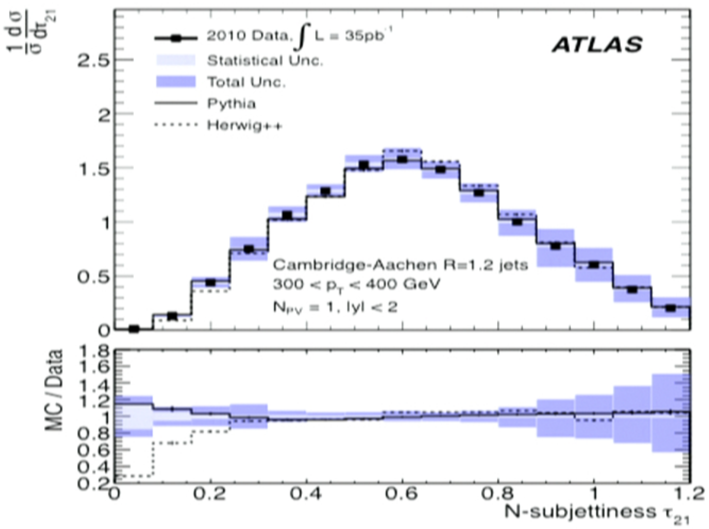
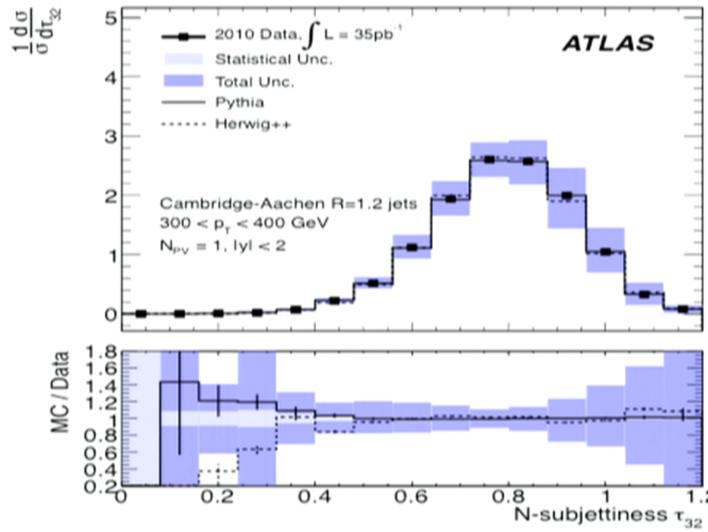


Oh, Data

hep-ex/1203.4606





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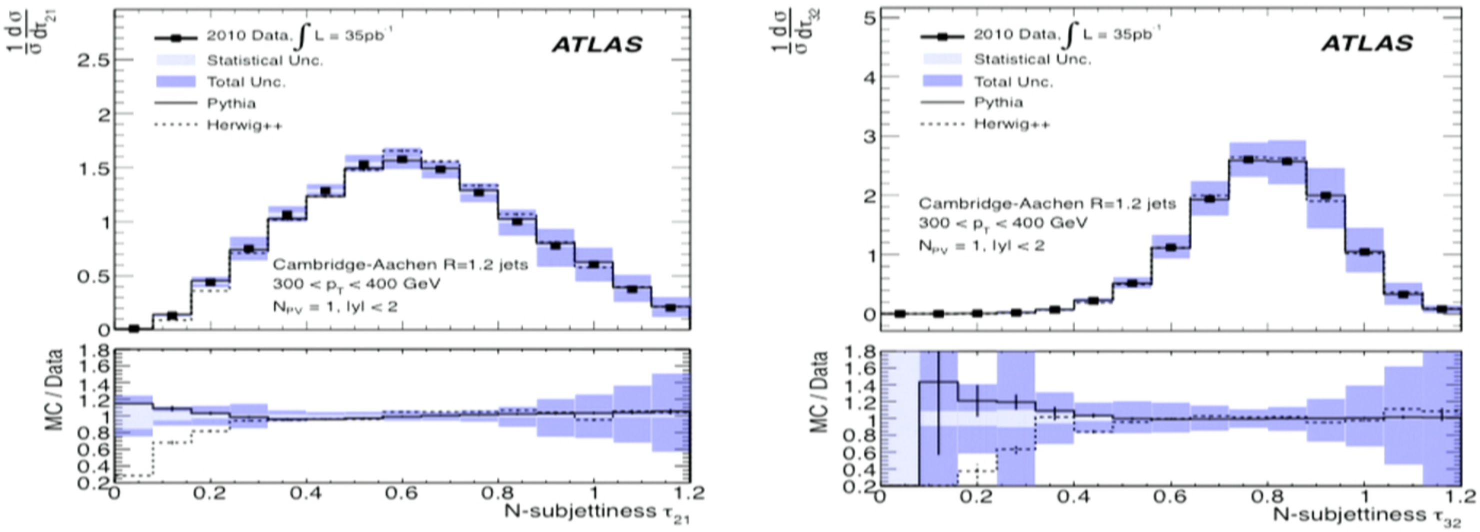
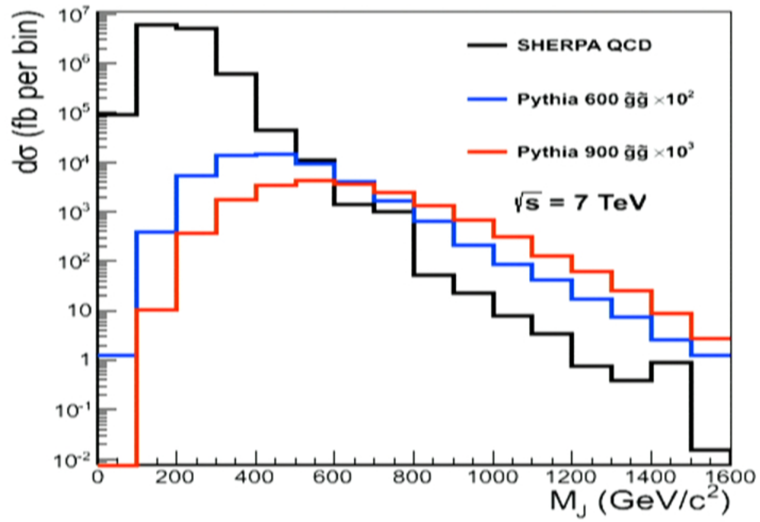


Approach

What does this do to signal?

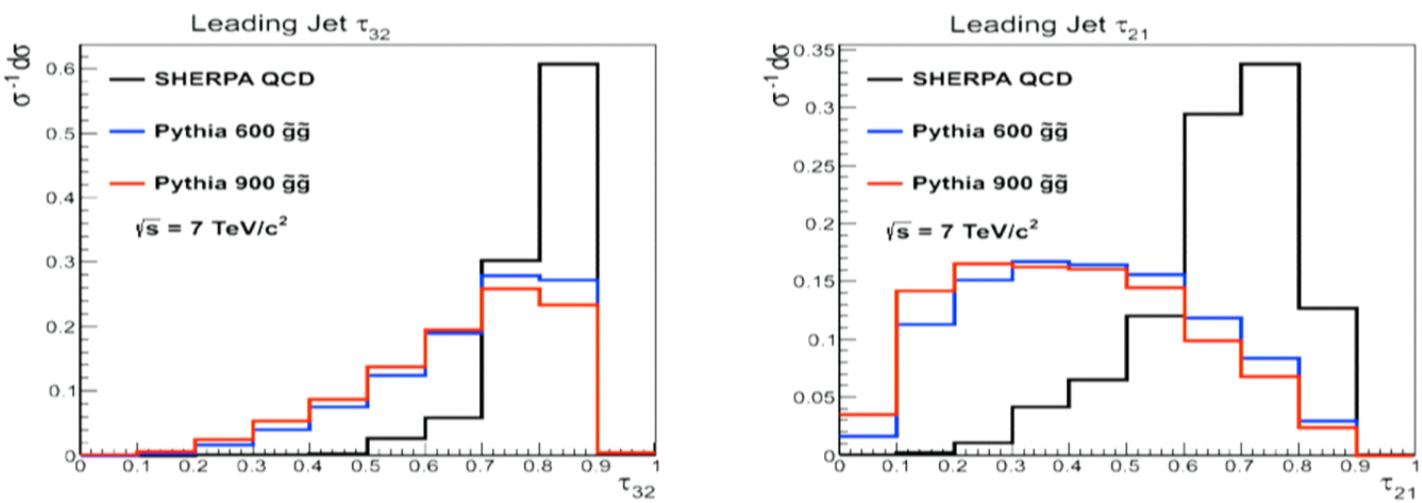
M_J ok discriminator



Approach

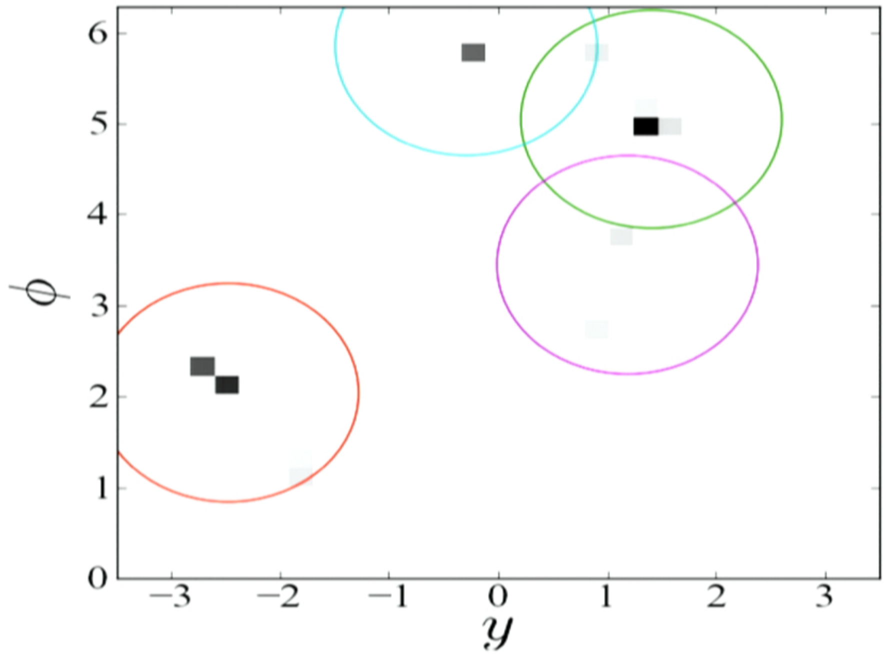
How about looking at substructure?

$$\tau_{NM} \equiv \tau_N/\tau_M$$

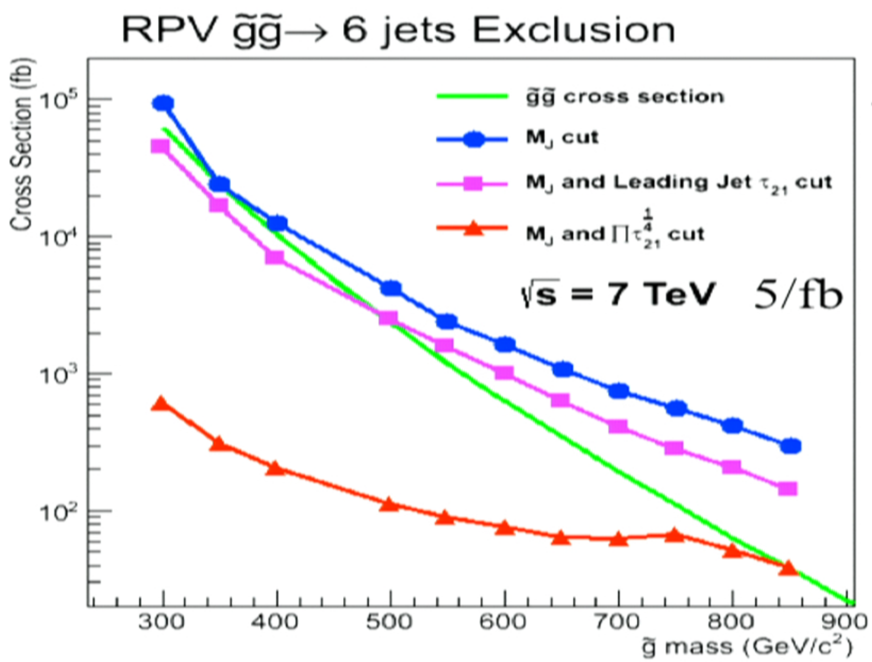


Approach

What's happening?
QCD



What can the LHC tell us?



20% Syst